EUROPA'S CRATERS AND PITS: PRELIMINARY INSIGHTS FROM THE FIRST ORBITS OF GALILEO. W. J. Merline, C. R. Chapman, B. Bierhaus, J. Keller, S. Brooks (Southwest Research Institute), A. McEwen (Lunar and Planetary Laboratory, University of Arizona), R. Sullivan, R. Greeley, K. Bender (Arizona State University), M. Carr (USGS, Menlo Park), C. Pilcher (NASA Headquarters), and the Galileo Imaging Team.

Imaging data from Galileo's first four orbits of Jupiter have begun to provide clues to the prevalence and nature of circular-depression features on the surface of Europa. Images have been acquired of highly spatially-selective regions, with resolutions ranging from the 1.6 km/pixel (slightly better than Voyager) in the first orbit (G1) to as high as 26 m/pixel in the fourth orbit (E4). These data indicate a distinct deficiency of impact craters at all sizes, relative to the outer Galilean satellites, and point toward at least two populations of circular-depression features. One class is composed of those features that are clearly impact craters, reflecting what appears to be a steeply sloping production population of impactors. The other is a class of shallow, weak-rimmed depressions (pits), having a monomodal size distribution, that are likely to be endogenic in origin.

Background: One of the surprises revealed by Voyager was Europa's lack of impact craters. Shoemaker and Wolfe (1982) suggested that the absence of craters on Europa might be related to viscous relaxation in an icy crust on top of an ocean, a concept that was then being developed. Shoemaker (1996, Europa Oceans Conf., San Juan Capistrano) further developed the idea that the size distribution of Europa's pits on Galileo's G1 images supported the now-popular idea that Europa has a subcrustal ocean.

In this paper, we describe analyses we have performed indicating that many of the craterlike pits, visible in the near-terminator images of the medium-resolution images of orbit G1, are likely to be of endogenic (rather than impact) origin. This, therefore, calls into question inferences based on the hypothesis of Shoemaker (1996) that they are degraded impact craters and that the virtual absence of yet larger craters is due to viscous relaxation in a thin ice crust. We have also measured, in the higher-resolution images from orbit E4, those features that can be unequivocally indentified as impact craters. We find that the craters, down to sizes at least as small as several hundred meters in diameter, are very rare, implying that Europa's surface (at least those areas studied so far) is relatively youthful and, in fact, may be currently active.

Large Features: The Galileo images have confirmed impressions that there are a few (but only a few) large impact craters. In particular, Belton et al. (1996, *Nature*, *274*, 377) have noted an apparent crater having diameter 30 km. Belton et al. also call attention to ray features that appear to emanate from a feature (named Pwyll) that is poorly resolved in Voyager imagery. New coverage of these longitudes during Galileo's second orbit (G2) confirm that Pwyll is a prominent ray crater of diameter 50 km (Greeley et al., this volume).

In addition to the rare large craters, near-terminator portions of the Europa images show hundreds of smaller (i.e., several-kilometer-sized) craters, pits, and depressions. Most of the features are shallow, approximately circular pits, which may or may not be degraded impact craters.

We have measured the size distribution of these features, down to the limits of resolution, in three areas of the medium-resolution images of orbits G1 (resolution 1.6 km/pixel) and C3 (resolution 420 m/pixel). Most pits are within the range 5–10 km in diameter, with the largest being 20 km across. Differential size-frequency relationships are plotted in Chapman et al. (this volume) in Relative-plot (R-plot) format. The curves show distinct rollover at diameters smaller than about 8 km, substantially above what would be expected from incompleteness due to resolution.

The slope (differential power-law index) of the size distribution at diameters in excess of the turnover point (8 km) is about –6, much steeper than any known size distributions for interplanetary bodies or for any observed crater distributions on other bodies. Therefore, if these pits are impact craters, then there must be a preferential loss mechanism for larger sizes, as suggested by Shoemaker (1996). His interpretation is that viscous relaxation in a thin ice crust will tend to erase larger features. A preferential loss mechanism for small craters may also be required.

A more straightforward explanation for the apparent monomodal size distribution is that it **is** monomodal—that pits have formed, for example, endogenically, with a preferred size of about 8 km. Monomodal size distributions of this form are common for geological features (e.g., dolines or drumlins).

Smaller Features: Size-frequency distributions for craters were determined for two regions of the high-resolution E4 Macula sequence. The result (also shown in Chapman et al. [this volume]) is a steeply sloping (differential power-law index of –4) distribution, reminiscent of production populations on other relatively young surfaces, e.g., asteroid Gaspra and Ganymede's Uruk Sulcus. The spatial density, however, is nearly two orders of magnitude below that expected for a saturated surface (e.g., asteroid Ida) at all sizes, and perhaps one order of magnitude below that seen on the "young" surfaces measured on Ganymede (although these "young" surfaces on Ganymede may be older than 3 Gyr). An important morphological difference between the larger depressions, seen in the lower-resolution images, and these features seen at high resolution, is that the smaller features are clearly impact craters, with well-defined, raised rims, in general. In the high-resolution images, there is a distinct absence of the type of shallow, weak-rimmed morphology characteristic of the larger depressions.

Overlap Relationships: We sought further insight about the cratering history on Europa by studying the spatial relationships between the observed pits and the numerous lineaments (of all types)—triple bands, ridges, cracks, and stripes—that dominate Europa's surface. Our initial goal was to determine whether the pits postdate or predate the lineaments by cataloging all overlapping relationships between them. However, despite the numerous pits and lineaments in four study regions, we found few clear cases of pits overlapping preexisting lineaments or of lineaments crosscutting across preexisting pits.

We found the number of intersecting relationships to be surprisingly few and, therefore, tried to estimate the number of intersecting relationships to be expected, if pits and lineaments are distributed spatially at random. First, we measured the areas of all clearly recognized bands and ridges in two regions of the medium-resolution images. About 15% of the area of the measured frames is consumed by recognizable lineaments. If the pits were simply points, we would expect about 15% of them to occur on the area occupied by lineaments. That would be 4.5 and 11 occurrences for the two regions measured. The integrated areas of the pits in these regions are 2.2% and 4.3% of the regions respectively, resulting in an expectation that 0.3% and 0.65% of the regions would be intersecting lineaments and pits. Given the fraction of the region occupied by an 8-km pit, one would expect a minimum of 7 or 12 pits involved in overlaps. This compares with only one clear-cut case for each of the regions (two other cases are marginal).

Our conclusion is that pits tend to avoid lineaments, or vice versa. This would be incompatible with impact craters formed wholly or partially after the lineaments. But it is not necessarily incompatible with lineaments forming in a preexisting impact crater field. One can imagine that preexisting craters might modify the crust in such a way the lineaments would avoid craters, although several larger impact craters seen on Europa seem to have lineaments radiating from them. One can also imagine that endogenic features might tend to prohibit formation of lineaments. Clearly, if there is an endogenic feature present, both the surface and subsurface at that point must be structurally different than the immediate surroundings.

The arrival of the high-resolution images from orbit E4 has allowed us to test our ideas, developed from our experience with the medium-resolution images, concerning the relationship between pits, craters, and lineaments (as well as the size distributions). In these high-resolution images, we can clearly see many cases of overlap of depression features and lineaments. However, now the depressions are clearly craters, not the morphologically indistinct pits measured above. Cases of craters overlying ridges, as well as cases of craters being sheared by lateral movement along cracks are clearly evident.

Summary: The two attributes of pits described above (monomodal size and avoidance of lineaments) strongly suggests that the large majority of the pits (sizes 5–10 km) are of endogenic origin (e.g., collapse features). Nonetheless, at smaller scales, there are many impact craters on Europa, apparently the result of a production population of impactors, although the density is low enough to indicate that the surface of Europa is young, much younger than that of even the youngest surfaces measured on Ganymede. However, because of large uncertainties in both the relevant production function for the Galilean satellites and the change in impact rates over geologic time, we cannot make estimates of the absolute ages of the surfaces to better than an order of magnitude.